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DEVELOPMENT OF WAXY AND PARTIALLY WAXY DURUM WHEAT FOR TESTING POTENTIAL END-USES

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"DEVELOPMENT OF WAXY AND PARTIALLY WAXY DURUM WHEAT FOR TESTING POTENTIAL END-USES"

Final Report

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ABSTRACT

Partially waxy durum wheat appears to have more potential for pasta production than does fully waxy durum wheat. Fully waxy durum wheat may have potential for flour or starch blending purposes. The latter uses need to be explored with following the development of an agronomically adapted waxy durum wheat. In excess of 2,200 doubled haploid lines of durum varying in amylose content were developed over the course of this project. In excess of 400 partially waxy lines were identified after an initial culling based on agronomic performance. A number of the partially waxy lines produced pasta-like product that had a shorter cooking (-12%) time and lower cooking losses than conventional durum. The potential energy savings, when multiplied over pasta-consuming households could be significant. This facet of partially waxy wheat needs to be more extensively studied to confirm or refute our findings

EXECUTIVE SUMMARY

The field evaluation of 44 fully waxy durum lines identified three that were within 5-12% of the grain yield of the check cultivars. This was a marked improvement over lines that had one less dose of durum parentage in their pedigrees. The development of doubled-haploid fully waxy durum lines led to the identification of a number of higher yielding lines in 2002. However, due to the extreme drought conditions encountered, these lines will need to be more widely tested in order to assess their agronomic merit.

All the pasta samples made from fully waxy durum had a totally different texture relative to CWAD wheat. The protein level of the fully waxy durum samples was high. The higher protein level, however, was not reflected in the pasta quality. The appearance of the waxy durum pasta was generally deemed acceptable, although some samples showed more specks and some had a dull color. Apart from the texture and sensory quality, there were some differences among waxy durum samples. Based on the color/speck of the dried/cooked pasta, a number of the waxy durum lines appeared to be superior to other waxy durum lines. A series of 467 partially waxy durum lines were identified via gel electrophoresis. Seed of these lines was multiplied in 2002. A subset of these lines was evaluated for pasta quality. Partially waxy durum lines were more suitable for pasta production compared to completely waxy lines. Among the 16 partially waxy samples tested for pasta quality one had a desirable yellow color, with better-balanced sensory quality (firmness, springiness, glutinosity) scores compared to the CWAD controls. Another line had the desired firmness and springiness with glutinosity, but its cooked pasta had a slightly duller color and was less yellow. Since this sample had a very high protein content its rheological characteristics may not be the same at a lower protein level. One of the partially waxy lines appeared to be preferable for pasta-like products and should be tested in a larger-scale evaluation. The SDS-PAGE band A and B lines were not significantly different in cooking and sensory characteristics.

TECHNICAL REPORT

BACKGROUND AND OBJECTIVES

Worldwide starch production has been growing at over 6 % per year since 1986 and was forecast to continue at this pace to the year 2001 (Decision Resources, Inc. 1997). In Canada about 66 to 75% of starch is used for industrial purposes. Specialty starches and novel uses of starch have broadened

marketing opportunities. Starches are used in a wide array of processed foods as thickeners and flavor enhancers. Starches have industrial applications such as in building adhesives, paper manufacture (cardboard, tissue paper, loose-fill packaging), and detergents. Eco-Foam is a 99% corn starch, water soluble packaging material produced by National Starch and Chemical. Efforts in the development of waxy hexaploid wheat have taken place in the USA, Australia, and Japan.

Development of a specialty starches, especially for industrial use may provide a new industrial activity in Saskatchewan. Opportunities to work with the Canadian paper industry may exist. Currently, starch for cardboard producers is obtained from corn starch manufacturers in Ontario. Waxy wheat starch absorbs much more water, stays gooey after heating and cooling, and doesn't lose water when frozen and thawed (C. Morris, personal communication). These criteria are useful in the food ingredients industry. Preliminary analysis of waxy durum wheat for making spaghetti suggested that completely waxy durum is not appropriate as it makes a softer product which is counter to what is considered quality spaghetti. Modification of relative amylopectin/amylose ratios may be appropriate to some industry users. Viscosity, shear resistance, gelatinization, texture, solubility, tackiness, gel stability, cold swelling and retrogradation are all functions of the amylose/amylopectin ratio of a starch. Producing a fully waxy wheat starch offers the industrial wheat starch user the opportunity to modify the amylose/amylopectin ratio in the range of 75% to 100% amylopectin.

Waxy wheat refers to the endosperm starch composition that is predominantly amylopectin which differs from typical wheat starch composition of 75% amylopectin and 25% amylose. Six durum crosses were processed through the University of Saskatchewan doubled haploid (DH) program using a modified protocol (Hatta et al., unpublished). The genes controlling the waxy trait were introduced into an adapted genetic background (about 94% durum).

This project was geared to support the development of fully waxy and partially waxy breeding material beyond the production of doubled haploids to a point where the waxy trait is established in an agronomically adapted background and provide sufficient quantities of seed for end-use testing.

No industrial non-food users have been identified yet that may be interested in waxy durum wheat. However, the ability to modify amylose/amylopectin ratios in starch appears to be very important to match starch composition with a process or product.

EXPERIMENTAL METHODS

A set of 44 fully waxy durum lines was evaluated in a three-replication RCBD field trial at three sites in 2000. These lines were obtained from populations developed at the CDC and the Tohoku Agricultural Experimental Station (TNAES) of MAFF Japan. The waxy trait was transferred from common wheat (K107) to durum by T. Nakamura. The material field tested in 2000 contained 3 doses of durum parentage. The 44 fully waxy durum lines were subjected to preliminary quality evaluations at the University of Saskatchewan. Based on the test results a subset of 11 lines and 5 check cultivars was sent to Nippon Flour Mills (NiPPN) for detailed analysis in 2001. Fifteen of the lines initially tested in 2000 were retested at four sites using a 3-rep RCBD in 2002.

A new series of BC_2 lines was evaluated in 2001. These 96 lines were selected from 607 lines grown in unreplicated 3.6- meter rows in 2000. The lines grown in 2000 were selected stringently for increased test weight. The 96 lines were grown at three sites in 2001, with a single-replicate plot at each site. None of those lines were fully waxy when subjected to predictive lab tests. These lines were thus not retested in 2002.

Doubled haploid lines from six crosses were developed in 1999-2000. Three crosses are structured as AC Avonlea*2/WD23 and the other three as D97437//AC Avonlea/WD23 where WD23 = Sceptre//K107/Aldura, AC Avonlea is a 1997 durum cultivar release, and D97437 is a high yielding, low cadmium uptake durum line. An initial series of 167 DH lines were generated in the spring of 2000. These lines were increased in New Zealand in 2000/2001. Another 2,158 lines were generated during the summer and fall of 2000. These lines were grown out as DH2's in winter greenhouse production at Saskatoon and Elrose, SK.. The 2,158 lines were grown in 3 m rows at Saskatoon during the summer of 2001. Approximately 60% of the lines were harvested after culling for plant-type, maturity, height and leaf retention. The DH lines were visually screened for the fully waxy phenotype. Lines that were not fully waxy were subjected to SDS PAGE analysis to determine whether lines were partially waxy or wild type (non-waxy). Genotyping for the presence of the wx-A1 and wx-B1 alleles at their respective loci on chromosomes 7A and 4A was performed using the protocol described by Zhao et al. (1996). The expected distribution of each population was 25% Wx-A1/Wx-B1 : 25% Wx-A1/wx-B1 : 25% wx-A1/Wx-B1 : 25% wx-A1/wx-B1. One of the advantages of tetraploid waxy germplasm is that the waxy trait has simpler inheritance being controlled by two loci rather than three as is the case with hexaploid waxy wheat. Of the lines grown in 2001; 100 partially waxy lines were sent to Nippon Flour Mills for evaluation in 2002.

The partially waxy lines were grown in unreplicated 3.6 m increase plots in 2002. Fully waxy lines were grown in a series of four 2-replicate yield trials at Saskatoon in 2002.

The NiPPN Central Quality Laboratory evaluated fully waxy durum lines in 2001 and partially waxy durum lines in 2002. The objective was to determine how the presence of the fully or partially waxy traits affected pasta quality.

Detailed analysis (NiPPN) of fully waxy durums grown in 2000:

For reference purposes, a commercial CWAD cargo sample was added to the sample set. Wheat samples were milled with Brabender Quadrumat Jr. and straight grade flour samples were obtained.

CWAD samples:

Ref CWAD Commercial Cargo, #45 KYLE, #46 AC MORSE,
#47 AC NAVIGATOR, #48 AC MELITA, #49 AC AVONLEA,

Waxy Durum:

#04 DT661/Wxdur26-5, #06 DT661/Wxdur26-11, #07 DT661/Wxdur26-12,
#09 DT661/Wxdur26-22, #14 DT661/Wxdur33-7, #29 JWD-230,
#31 JWD-230, #35 JWD-239, #39 JWD-119,
#41 JWD-188, #43 JWD-238,

Pasta processing was performed using an established NIPPN laboratory protocol. Sensory quality of the pasta was evaluated by four panels. Pasta was cooked in boiling water (no salt) for the time listed below, cooked pasta were drained. The reference sample (CWAD) was scored a "4" for each test parameter. The cooking time for each pasta sample was determined based on a preliminary test.

Pasta cooking times for 2000 crop year grain samples.

No	CWAD	No.45	No.46	No.47	No.48	No.49	No.4	No.6	No.7
Time	8'30"	9'30"	9'30"	9'00"	9'30"	9'30"	7'00"	7'00"	7'30"
Sample no.	No.9	No.14	No.29	No.31	No.35	No.39	No.41	No.43	
Time	7'30"	7'30"	7'30"	7'00"	7'30"	7'30"	7'30"	7'30"	

Detailed analysis (NIPPN) of partially waxy durum DH lines grown in 2001:

We added a CWAD commercial cargo sample as a reference to the 18 tested samples. Wheat samples were milled with Brabender Quadrumat Jr. and straight grade flour samples were obtained.

Conventional Durum:

Ref-CWAD Commercial Cargo, #101-F4525-Melita, #106-F4575-Avonlea

Partially waxy Durum:

SDS-PAGE band A present

#003-F4573, #017-F4620, #029-F4658, #058-F4713, #073-F4748,
#079-F5297, #084-F5346, #094-F5640

SDS-PAGE band B present

#001-F4571, #012-F4613, #018-F4622, #030-F4657, #048-F4696,
#066-F4731, #085-F5363, #095-F5642

Sensory quality of the pasta was evaluated by 3 panels. Pasta samples were cooked in boiling water (no salt) for the time listed below, cooked pasta were drained. The reference sample (CWAD) was set at "all 4 points". (Score "1" being "not preferable" to "7" being "preferable".) The cooking time for each pasta samples were determined by preliminary test.

No	#003	#017	#029	#058	#073	#079	#084	#094
Cooking Time	8'30"	8'00"	8'30"	8'30"	8'30"	9'30"	9'30"	9'30"
No.	#001	#012	#018	#030	#048	#066	#085	#095
Cooking Time	8'30"	8'30"	8'30"	8'00"	8'30"	8'30"	9'30"	9'30"
No	#101	#106	CWAD					
Cooking Time	9'00"	9'00"	9'00"					

RESULTS

1.a. Agronomic evaluation of waxy durum lines in 2000 and 2002

A set of 44 fully waxy durum lines was evaluated in a three-replication RCBD field trial at three sites in 2000 (Table 1). Approximately a third of the lines yielded within the range of the check cultivars (Entries 45 to 49). The waxy lines represented material that had been backcrossed twice to durum. Lines (n=23) derived from a single back-cross to durum were evaluated at five sites in 1999 (data not presented). The BC1 lines yielded on average 26% less than the check cultivars, Plenty and Sceptre, in 1999. Thus, the performance of the BC_2 lines evaluated in 2000 was a significant improvement over previously available material.

The 44 lines evaluated in 2000 tended to have lower test weights and kernel weights than the check cultivars. None of the lines combined the desired grain yield, test weight, kernel weight, protein content and gluten strength (SDS sedimentation) and were thus not advanced for further testing in 2001.

A second series of BC_2 lines was evaluated in 2001. These 96 lines were grown at three sites in, with a single-replicate plot at each site. None of those lines were fully waxy when subjected to predictive lab tests. These lines were thus not retested in 2002. Instead, 16 lines initially tested in 2001 were retested in 2002 in order to identify the most agronomically promising fully waxy lines. After culling the 16 lines, three remained (Table 2). These three lines yielded 5-12% less than the mean of the four check cultivars, indicating that further backcrossing will be required to develop agronomically competitive

waxy durum cultivars.

Results from the field evaluation of fully waxy DH lines tested in 2002 are presented in Table 3. Due to the drought conditions encountered, care needs to be taken in interpreting the results. Nonetheless the 262 lines were culled down to less than 30, based on six traits. This material will need to be re-evaluated in a multi-site test.

Table 1. Agronomic performance of 44 fully waxy durum wheat lines, averaged over three locations, 2000

Entry	Pedigree	Yield g/plot	Yield % AVNL	Height cm	Maturity days	TWT kg/hl	KWT grams	PRO %	SDS cc
49	AC AVONLEA	1894	**100**	98.0	110.3	78.4	45.3	17.3	35.3
45	KYLE	1819	**96**	104.0	109.3	79.0	43.4	16.4	31.3
46	AC MORSE	1836	**97**	86.3	109.0	78.2	43.4	16.4	40.0
47	AC NAVIGATOR	1953	**103**	79.5	108.3	80.4	43.3	14.9	42.0
48	AC MELITA	1849	**98**	94.3	109.0	79.6	47.1	16.1	47.8
1	DT661/WXDUR 3-7	1703	**90**	101.5	109.5	76.7	35.8	16.6	21.5
2	DT661/WXDUR 11-8	1656	**87**	101.5	109.3	77.4	43.0	16.9	24.5
3	DT661/WXDUR 19	1680	**89**	91.8	108.8	77.7	39.2	16.6	22.5
4	DT661/WXDUR 26-5	1831	**97**	85.8	110.0	78.7	38.9	15.9	28.5
5	DT661/WXDUR 26-10	1810	**96**	91.5	110.0	77.1	42.2	15.8	30.8
6	DT661/WXDUR 26-11	1883	**99**	97.5	108.5	77.8	40.4	16.5	41.5
7	DT661/WXDUR 26-12	1787	**94**	89.0	109.5	77.9	57.1	16.3	45.3
8	DT661/WXDUR 26-14	1860	**98**	89.3	110.3	61.5	40.0	16.3	28.0
9	DT661/WXDUR 26-22	1789	**94**	83.3	109.8	77.9	37.7	16.2	31.5
10	DT661/WXDUR 26-29	1745	**92**	88.8	110.5	76.7	39.9	16.3	31.5
11	DT661/WXDUR 31-1	1798	**95**	86.0	108.3	74.3	35.8	16.6	39.3
12	DT661/WXDUR 31-2	1989	**105**	91.8	110.5	74.9	38.4	15.2	34.3
13	DT661/WXDUR 31-5	1756	**93**	84.0	108.3	75.7	35.6	15.3	40.0
14	DT661/WXDUR 33-7	1995	**105**	94.8	110.0	77.4	42.1	15.8	22.5
15	DT661/WXDUR 33-8	1777	**94**	97.5	109.3	75.7	38.9	16.1	32.0
16	DT661/WXDUR 33-23	1825	**96**	93.5	110.0	76.3	34.1	16.1	30.8
17	JWD-73	1637	**86**	97.0	110.3	78.3	35.8	16.7	40.3
18	JWD-106	1783	**94**	84.8	109.3	76.1	39.5	15.3	38.3
19	JWD-114	1667	**88**	92.8	109.0	78.1	40.5	16.2	32.8
20	JWD-121	1854	**98**	96.0	108.0	78.1	42.2	15.2	33.5
21	JWD-144	1785	**94**	108.0	109.5	77.7	40.4	15.6	22.5
22	JWD-145	1743	**92**	100.5	106.3	78.3	37.4	16.2	20.0
23	JWD-184	1802	**95**	101.0	108.8	77.8	40.2	16.0	23.5
24	JWD-194	1784	**94**	95.0	107.5	79.2	40.5	15.9	24.0
25	JWD-218	1714	**90**	97.0	108.8	78.0	38.9	15.6	33.5
26	JWD-222	1739	**92**	95.3	108.5	76.6	37.9	15.3	33.5
27	JWD-228	1734	**92**	93.8	108.0	78.6	41.7	15.2	33.3
28	JWD-229	1788	**94**	91.3	107.5	76.4	38.4	15.5	39.3
29	JWD-230	1953	**103**	95.3	109.3	77.6	42.7	15.4	30.0
30	JWD-230	1851	**98**	94.0	109.0	78.6	39.5	14.3	29.0
31	JWD-230	1958	**103**	96.3	107.5	77.5	38.9	14.7	28.0
32	JWD-235	1698	**90**	95.5	105.8	77.2	44.5	15.4	28.0
33	JWD-237	1778	**94**	96.8	108.5	76.9	46.0	15.8	34.3
34	JWD-238	1610	**85**	85.5	107.8	77.2	39.4	15.5	28.8
35	JWD-239	1783	**94**	95.5	109.0	78.2	40.3	15.5	28.3
36	JWD-240	1711	**90**	96.8	110.3	76.8	42.0	15.6	29.8
37	DT661/WXDUR 11-2	1658	**88**	100.3	110.3	76.9	36.4	18.1	29.3
38	DT661/WXDUR 11-13	1599	**84**	100.0	110.0	78.8	41.8	16.9	26.3
39	JWD-119	1852	**98**	88.0	108.0	79.1	41.0	15.1	28.0
40	JWD-122	1748	**92**	85.8	108.3	75.3	37.9	16.0	26.5
41	JWD-188	1805	**95**	99.8	108.0	78.4	40.6	16.5	22.0
42	JWD-223	1696	**90**	80.5	107.5	76.3	40.9	15.5	28.5
43	JWD-238	1790	**94**	93.3	107.3	77.5	39.2	15.9	28.5
44	JWD-262	1712	**90**	90.5	106.0	77.7	39.3	15.4	30.8

Table 2. Agronomic performance of 16 fully waxy durum wheat lines, averaged over four locations, 2002

ID	NAME	Yield kg/ha	Heading days	Maturity days	Height cm	Leaf Blight 1 to 9	Test wt kg/hL	Kern. Wt mg	Protein %	Ypig
AC AVONLEA		2048	53.0	96.3	56.3	6.0	78.0	43.0	16.8	6.8
KYLE		1769	55.3	96.5	62.8	5.5	77.3	42.0	17.5	5.9
AC MORSE		1928	54.5	96.8	57.0	5.0	76.6	38.1	15.9	6.8
AC NAVIGATOR		1998	54.5	99.0	55.5	3.5	77.8	43.0	16.2	7.5
00WXDUR3	DT661/WXDUR 26-11	1710	54.0	94.0	58.8	6.5	77.2	37.5	16.2	6.1
00WXDUR6	DT661/WXDUR 33-7	1868	54.8	97.3	56.0	6.5	76.4	38.6	15.8	7.4
00WXDUR8	JWD-144	1753	55.0	94.3	64.5	7.5	76.8	37.9	15.8	6.6
	No. of sites	4	2	2	2	1	4	4	3	3

Table 3. Agronomic performance of fully waxy durum DH wheat lines grown at one location, 2002.

ENTRY	ID	02wxduryt2	Yield % AVL	Test wt kg/hL	Kern. Wt mg	Protein %	Ypig	SDS sed cc
1	AC Avonlea		100.0	0.0	0.0	0.0	0.0	0.0
2	AC Navigator		91.6	-3.2	3.0	0.1	0.6	4.5
7	02WXDUR5	WD0201H-003	102.3	-2.6	-1.2	-0.4	0.1	-1.0
14	02WXDUR12	WD0203H-046	100.9	-3.5	-1.7	0.4	0.0	-2.5
18	02WXDUR16	WD0302H-003	94.0	-2.4	-0.5	0.0	-0.3	1.5
20	02WXDUR18	WD0504H-012	103.7	-2.5	-1.7	0.5	0.0	1.5
21	02WXDUR19	WD0303H-016	99.5	-2.8	-2.7	0.6	-0.1	1.5
22	02WXDUR20	WD0304H-018	111.6	-1.4	1.1	-0.1	0.7	-3.5
33	02WXDUR31	WD0510H-034	110.3	-2.3	1.0	-0.5	-0.4	3.5
36	02WXDUR34	WD0512H-008	93.8	-2.3	-0.5	0.2	-0.9	6.5
37	02WXDUR35	WD0512H-017	107.5	-3.0	0.2	-0.8	0.0	7.5
40	02WXDUR38	WD0601H-011	97.4	-1.1	-0.1	0.1	0.2	1.5
50	02WXDUR48	WD0128H-015	112.7	-1.4	-2.7	-0.7	-0.7	-2.0
61	02WXDUR59	WD0223H-005	122.7	-1.8	-2.0	-0.9	-0.9	5.5

		02wxduryt3	Yield % AVL	Test wt kg/hL	Kern. Wt mg	Protein %	Ypig	SDS sed cc
1	AC Avonlea		100.0	0.0	0.0	0.0	0.0	0.0
2	AC Navigator		93.5	-2.0	6.1	-0.4	0.5	6.5
35	02WXDUR95	WD0325H-043	90.5	-2.3	-2.5	0.3	0.2	3.5
39	02WXDUR99	WD0326H-035	86.3	-2.2	-2.1	-0.3	0.1	2.0

		02wxduryt4	Yield % AVL	Test wt kg/hL	Kern. Wt mg	Protein %	Ypig	SDS sed cc
1	AC Avonlea		100.0	0.0	0.0	0.0	0.0	0.0
2	AC Navigator		85.7	-3.3	4.8	0.2	0.8	5.0
61	02WXDUR183	WD0620H-085	80.6	-1.8	6.1	0.6	0.0	3.0
62	02WXDUR184	WD0620H-088	94.6	-1.9	6.3	0.5	-0.1	-1.0

		02wxduryt5	Yield % AVL	Test wt kg/hL	Kern. Wt mg	Protein %	Ypig	SDS sed cc
1	AC Avonlea		100.0	0.0	0.0	0.0	0.0	0.0
2	AC Navigator		64.6	-0.2	5.4	-0.6	-0.1	6.0
6	02WXDUR190	WD0622H-050	111.2	-0.8	3.2	-0.1	0.0	11.0
7	02WXDUR191	WD0622H-082	126.5	-1.0	0.5	-0.2	2.4	4.5
11	02WXDUR195	WD0623H-034	117.2	-1.1	2.6	-0.5	-0.3	7.5
14	02WXDUR198	WD0623H-091	110.8	-1.2	1.2	1.1	-1.0	3.0
23	02WXDUR207	WD0626H-062	106.5	-0.3	3.8	0.0	-1.2	8.0
25	02WXDUR209	WD0627H-007	130.5	-0.8	2.2	-1.0	0.6	3.0
27	02WXDUR211	WD0627H-064	106.9	0.0	1.6	-0.2	1.0	7.0
31	02WXDUR215	WD0627H-090	102.9	-1.5	2.3	-0.1	0.7	-0.5
32	02WXDUR216	WD0629H-001	92.8	-1.3	-0.5	0.2	1.7	7.0
33	02WXDUR217	WD0629H-029	112.6	-1.3	3.7	0.6	0.0	4.0
39	02WXDUR223	WD0632H-019	147.4	-0.2	7.0	-1.1	-1.2	5.0

1.b. Preliminary Quality evaluation of waxy durum lines grown in 2000

The 44 waxy durum lines evaluated in the field in 2000 were subjected to predictive quality analyses, mixograph and amylograph tests. The results are summarized in Table 4. The waxy lines tended to have faster-mixing doughs (Mixograph data) and amylograph properties similar to waxy common wheat. The lines were tested for alpha-amylase activity as the Falling Numbers on earlier waxy durums had been very low (~60 seconds). The enzyme activity of the waxy durums was lower than that of the controls. Hence, low falling numbers in waxy durum are likely a result of altered starch properties, not pre-harvest sprouting.

Table 4. Quality evaluation of 44 waxy durum lines and five check cultivars grown at Saskatoon, SK

TRAIT		Waxy durum lines n=44 Mean	SE	Durum checks n=5 Mean	SE
1000 KWT	grams	49.2	0.4	49.5	1.6
Grain Protein	%	14.8	0.1	14.5	0.7
SDS Sediment.	cc	31.4	1.1	34.3	3.9
PSI	%	29.1	0.7	27.8	0.7
Mixo. Develop. Time	min	1.86	0.09	2.45	0.3
Mixo. Peak Height	MU	61.1	1.0	56.4	1.5
Mixo. Slope	MU	-3.29	0.23	-2.73	0.45
Mixo. Band Width	MU	13.95	0.52	13.3	2.2
Total Energy	MU	365.5	3.7	332.4	8.8
Energy to Peak	MU	88.6	5.0	103.9	16.3
Amyl. Beg. Gel Temp	C	61.4	0.1	67.3	0.8
Amyl. Peak Viscosity	BU	178.7	6.9	435.2	39.7
Amylo. PV Temper.	C	68.2	0.1	91.8	0.4
Amylo. Start Cool Vis.	BU	64	3.7	319.6	49.7
Amylo. End Cool Vis.	BU	107.3	5.6	561.6	59.3
Amylo. Breakdown	BU	114.7	4.1	115.6	12.8
Amylo. Set-back	BU	43.3	2.1	242	13.1
Alpha amylase	calphaU	0.187	0.008	0.213	0.027

Mixo. = Mixograph; Amylo = Amylograph measurements.

1.c. Detailed quality analysis of 2000 Waxy Durums (NIPPN)

The grain samples were obtained from 2000 crop year CDC field trials grown in Saskatchewan, included five conventional durums (CWAD) and 11 waxy durum wheats. For reference purposes, a commercial CWAD cargo sample was added to the sample set.

Compared to the cargo CWAD sample, the conventional durum samples had higher wheat/flour ash contents. Waxy durum Nos. 6 and 14 were lower in wheat ash content, and No.14 was also lower in flour ash. Waxy durum samples Nos.9, 31, 35, 39 and 43 had high wheat/flour ash contents. All the grain and flour protein levels were higher than for the commercial CWAD cargo sample. Waxy durum protein levels were approximately of the same level as conventional durum samples. Of the waxy samples, No.31 was slightly lower in protein. SKCS hardness index values showed that waxy durum wheat samples were slightly softer than the conventional durum samples in kernel texture. Waxy durum samples were lower in flour yields, compared to the conventional durum. All the waxy flour samples had very low amylose levels. All the waxy durum samples were considered to have high amylase activity, which indicates that they have low tolerance for sprouting.

The amount of water added to the flour during mixing was 32% for the conventional durum, and 30% for the waxy durum. Among the conventional durum spaghetti, No.47 showed bright yellow color of dried pasta. Among the waxy durums, Nos.4, 7, 9 had many detectable specks, Nos.4, 7, 9, 35 and 39 had a slightly dull appearance. However, in general, they produced an acceptable pasta color. Although there were some differences between waxy durum samples in dough hardness during processing, there were no significant differences in eating quality between waxy samples. All the waxy durum pasta had a totally different texture from conventional durum pasta. Rheometer analysis also indicated that the waxy durum pasta had Japanese salted noodle (Udon) texture, rather than spaghetti texture.

Waxy durum produced spaghetti with a totally different texture from what one would expect from CWAD wheat. Although waxy durum samples had a higher protein content, the texture and sensory profile of waxy durum pasta did not reflect the protein level. The sensory quality of the waxy samples differed slightly, however, they were all different from CWAD pasta. Judging from pasta appearance and processing characteristics, Nos.6 or14 are considered to be the better of the waxy durum samples. However, sensory quality needs be improved, and the alpha-amylase levels need to be verified to establish whether the waxy durum lines had poorer sprouting tolerance (especially No.14).

The grain characteristics for the 2000 grain samples are summarized in Table 5.

Table 5. Grain Data – 2000 crop year samples

Sample	Moisture %	Ash % 13.5%mb	Protein % 13.5%mb	Test Wt g/L	Falling No. sec
Ref. CWAD Cargo	11.6	1.52	12.8	806	529
#45 Kyle	9.8	1.62	15.2	795	506
#46 AC Morse	9.8	1.66	15.2	787	683
#47 AC Navigator	9.9	1.65	14.1	804	500
#48 AC Melita	9.8	1.66	14.4	800	654
#49 AC Avonlea	9.7	1.65	15.5	791	532
#04 DT661/Wxd26-5	9.7	1.70	14.7	792	62
#06 DT661/Wxd26-11	9.7	1.60	15.1	785	61
#07 DT661/Wxd26-12	9.5	1.69	15.1	783	64
#09 DT661/Wxd26-22	9.7	1.74	15.2	783	63
#14 DT661/Wxd33-7	9.7	1.59	14.5	789	59
#29 JWD-230	9.6	1.66	14.2	778	62
#31 JWD-230	9.5	1.72	13.8	772	64
#35 JWD-239	9.7	1.74	14.4	774	60
#39 JWD-119	9.7	1.74	14.4	791	63
#41 JWD-188	9.7	1.64	15.0	786	60
#43 JWD-238	9.6	1.75	14.6	778	63

Except for nos. 6, 7, 14, 29, 41, waxy durums had higher ash content than the CWAD samples. Conventional durum had high FN values, however, all the waxy durum showed very low FN values. Waxy durum Nos.29, 31, 35, 43, had lower test weights. Compared to the cargo CWAD, all the samples were higher in protein content.

Table 6. Kernel hardness and dimensions for 2000 crop year samples.

Sample	SKCS			1000KW
	Hardness Index	Diameter mm	Weight mg	g
Ref. CWAD Cargo	94.8	2.6	39.1	40.9
#45 Kyle	88.2	2.8	43.3	43.4
#46 AC Morse	91.5	2.8	41.3	41.8
#47 AC Navigator	89.9	2.9	43.0	42.8
#48 AC Melita	90.3	3.0	45.2	45.7
#49 AC Avonlea	89.8	2.7	41.7	40.4
#04 DT661/Wxd26-5	80.9	2.4	34.3	34.8
#06 DT661/Wxd26-11	79.9	2.7	39.7	38.6
#07 DT661/Wxd26-12	77.0	2.6	39.8	40.4
#09 DT661/Wxd26-22	80.7	2.4	34.7	36.1
#14 DT661/Wxd33-7	78.1	2.7	40.0	39.4
#29 JWD-230	80.6	2.7	39.9	39.5
#31 JWD-230	81.6	2.6	38.0	37.6
#35 JWD-239	78.8	2.7	38.6	37.2
#39 JWD-119	82.3	2.7	39.9	42.5
#41 JWD-188	76.5	2.7	40.6	40.9
#43 JWD-238	81.8	2.6	38.1	37.7

1000 kernel weight, SKCS diameter and SKCS weight, indicate that grain of waxy durum Nos.4 & 9 are small, and Nos.31, 35, 43 are slightly smaller than the control samples. SKCS hardness indices indicated that the waxy durums had a softer endosperm than the conventional durums. No.35 had a wider hardness index distribution than the others (data not presented).

Table 7. Experimental Milling and Flour Data for 2000 crop samples.

Sample	Flour Yield %	Ash % 13.5%mb	Protein % 13.5%mb	Amylose % in Starch
Ref. CWAD Cargo	66.4	0.77	12.3	33.2
#45 Kyle	64.7	0.73	14.4	30.8
#46 AC Morse	62.2	0.72	14.4	34.1
#47 AC Navigator	66.1	0.73	13.2	30.9
#48 AC Melita	63.5	0.75	13.9	33.1
#49 AC Avonlea	63.3	0.72	14.8	32.5
#04 DT661/Wxd26-5	61.1	0.75	14.0	5.5
#06 DT661/Wxd26-11	60.1	0.76	14.6	5.7
#07 DT661/Wxd26-12	61.3	0.73	14.6	6.1
#09 DT661/Wxd26-22	56.3	0.79	14.8	5.1
#14 DT661/Wxd33-7	60.2	0.66	14.0	4.8
#29 JWD-230	61.2	0.79	13.8	4.9
#31 JWD-230	59.9	0.84	13.4	6.3
#35 JWD-239	61.8	0.85	13.8	6.2
#39 JWD-119	60.6	0.82	13.8	6.1
#41 JWD-188	62.2	0.73	14.4	5.9
#43 JWD-238	58.5	0.85	14.0	6.3

Waxy durum lines were characterized by a lower flour extraction compared to the CWAD samples. Sample No.14, which had a lower wheat ash content also had a lower flour ash content. Samples Nos.31, 35, 39, 43, which had a higher wheat ash also had a higher flour ash. The waxy durum samples had a very low amylose content.

Table 8. Flour paste color profiles.

	Flour	Paste	Color
Sample	L*	a*	b*
Ref. CWAD Cargo	86.86	-2.83	22.89
#45 Kyle	86.73	-2.77	21.72
#46 AC Morse	86.74	-2.98	23.97
#47 AC Navigator	86.68	-3.33	26.17
#48 AC Melita	87.18	-3.12	23.18
#49 AC Avonlea	86.42	-3.15	24.85
#04 DT661/Wxd26-5	85.75	-3.12	25.34
#06 DT661/Wxd26-11	86.52	-3.08	24.30
#07 DT661/Wxd26-12	86.17	-2.64	22.90
#09 DT661/Wxd26-22	85.88	-2.83	23.46
#14 DT661/Wxd33-7	86.40	-3.20	24.75
#29 JWD-230	86.95	-3.16	23.00
#31 JWD-230	86.98	-3.00	22.46
#35 JWD-239	86.52	-2.77	20.74
#39 JWD-119	86.22	-2.27	19.79
#41 JWD-188	86.53	-2.87	22.45
#43 JWD-238	86.41	-2.84	22.09

Flour paste color analysis indicated that sample No.47 (Navigator) had a very strong yellow color. Among the waxy samples, samples Nos.4 and 9 showed slightly lower L* values and Nos. 35 and 39 showed slightly lower b* values.

Table 9. Rapid Visco Analyzer data for 2000 crop year samples.

Sample	RVA (Distilled Water)				RVA (1mM AgNO3)			
	Peak Time min	Peak Visc. cP	Breakdown cP	Setback cP	Peak Time min	Peak Visc. cP	Breakdown cP	Setback cP
Ref. CWAD Cargo	5.9	2481	726	1463	6.0	2911	910	1550
#45 Kyle	5.8	2602	860	1499	6.0	3178	1024	1641
#46 AC Morse	5.6	2711	1064	1645	5.8	3339	1190	1732
#47 AC Navigator	5.5	2732	957	1885	5.9	3294	990	1899
#48 AC Melita	5.5	2549	973	1621	5.9	3052	995	1658
#49 AC Avonlea	5.3	2198	894	1479	5.7	3156	1130	1771
#04 DT661/Wxd26-5	3.5	1865	908	296	3.3	4171	2523	427
#06 DT661/Wxd26-11	3.5	1638	862	243	3.3	4341	2574	430
#07 DT661/Wxd26-12	3.5	2175	1149	344	3.2	4563	2913	427
#09 DT661/Wxd26-22	3.5	2062	962	285	3.3	4205	2489	396
#14 DT661/Wxd33-7	3.4	1024	613	159	3.3	4085	2514	428
#29 JWD-230	3.5	2052	1071	300	3.3	4349	2671	433
#31 JWD-230	3.5	1875	905	369	3.3	4254	2627	489
#35 JWD-239	3.5	1551	821	255	3.3	4220	2565	472
#39 JWD-119	3.4	1681	867	288	3.3	4011	2384	440
#41 JWD-188	3.3	1198	756	148	3.3	3817	2287	414
#43 JWD-238	3.5	1783	839	303	3.3	4293	2621	459

With AgNO3, waxy durum peak viscosity doubled. This may indicate that these waxy durums may have higher amylase activity, compared to the conventional durum wheat. With AgNO3, all the waxy durum lines had a higher early peak time, peak viscosity, larger breakdown, smaller setback, which are the characteristics of the waxy starch. Earlier peak time indicates that products made from the waxy durum will have shorter cooking time. The peak temperature (not shown) of waxy durum are around 80C, while all the conventional durum showed a peak during the 95C holding stage.

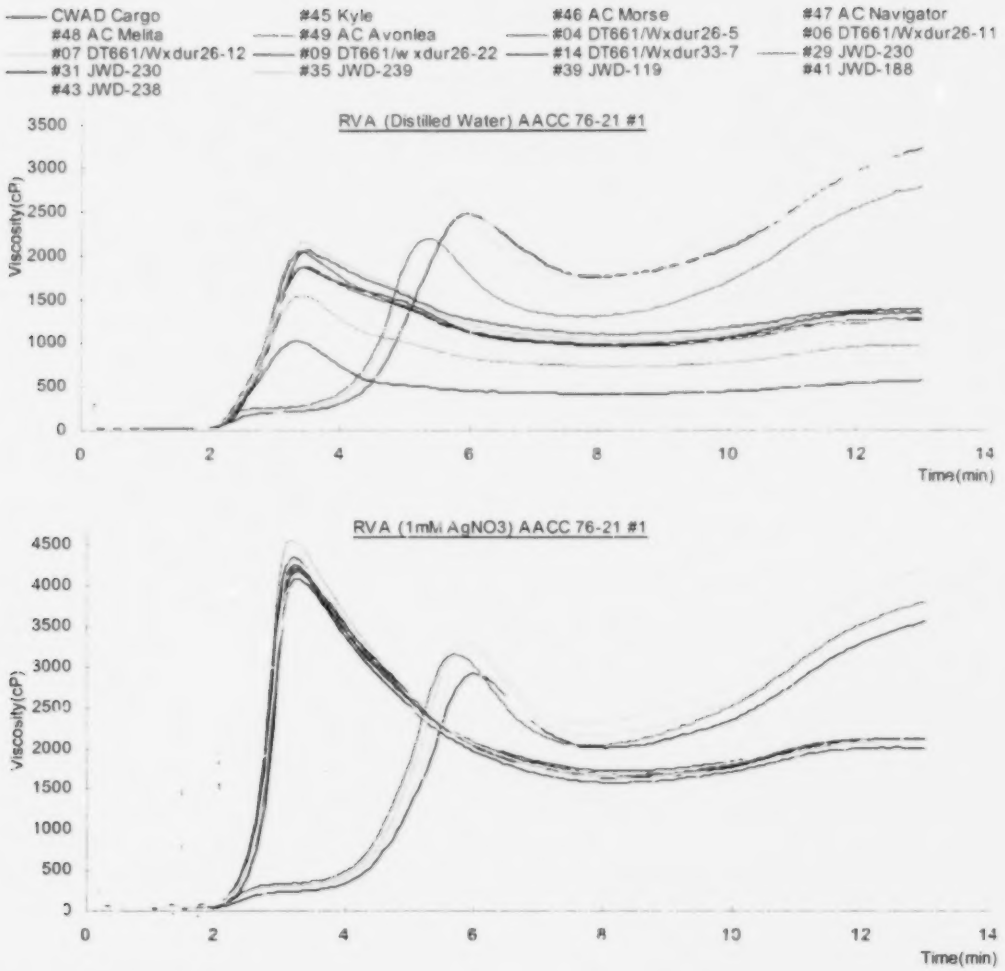


Figure 1. RVA profiles for 2000 crop year samples

Pasta processing was performed using a Farinograph small bowl. The amount of water added at the mixing stage was 32% for conventional durum, and 30% for the waxy durum (both at 16% flour mb). After mixing and during the extrusion process, waxy durum dough sample Nos.4,6,7,9,14 were rather harder while samples Nos. 29,31,35,39,43 were softer. Assuming from the time needed for extruding the pasta strand, although it was not accurately measured, doughs of waxy durum Nos.4,6,7,9,14,39, especially Nos.4,6,7,9, were hard, and Nos.31,35,43, especially No.31, were soft.

Table 10. Pasta dimensions

Pasta Sample	Moisture %	Diameter mm
Ref. CWAD Cargo	10.9	1.75
#45 Kyle	10.2	1.77
#46 AC Morse	10.2	1.76
#47 AC Navigator	10.0	1.71
#48 AC Melita	10.1	1.72
#49 AC Avonlea	10.2	1.76
#04 DT661/Wxd26-5	11.0	1.73
#06 DT661/Wxd26-11	10.9	1.73
#07 DT661/Wxd26-12	11.1	1.73
#09 DT661/Wxd26-22	11.1	1.74
#14 DT661/Wxd33-7	11.1	1.73
#29 JWD-230	11.1	1.72
#31 JWD-230	11.1	1.71
#35 JWD-239	10.5	1.72
#39 JWD-119	10.5	1.73
#41 JWD-188	10.4	1.73
#43 JWD-238	10.4	1.71

Pasta (spaghetti) from samples which gave a softer dough resulted in a smaller strand diameter. Both conventional durum and waxy durum showed this tendency. However, waxy durums which made a harder dough had a smaller spaghetti diameter compared to the harder dough CWAD samples. Dried pasta moisture of waxy samples Nos. 4, 6, 7, 9, 14, 29, 31 was higher than that from CWAD. This may indicate that waxy durum dough may have a higher water holding capacity. However, waxy durum samples Nos. 35, 39, 41, 43 had only a slightly higher pasta moisture level.

Table 11. Pasta color and cooking characteristics for 2000 crop year samples.

Sample	Dry Pasta Color			Cooking	
	L*	a*	b*	Loss %	Yield %
Ref. CWAD Cargo	49.0	-2.6	33.7	6.6	235.0
#45 Kyle	48.6	-3.1	30.9	7.2	245.0
#46 AC Morse	48.5	-3.0	32.3	6.6	240.0
#47 AC Navigator	47.1	-1.7	37.1	9.0	257.0
#48 AC Melita	49.2	-3.1	33.0	8.3	250.0
#49 AC Avonlea	48.2	-2.9	32.6	8.2	257.0
#04 DT661/Wxd26-5	49.5	-2.4	32.8	9.0	236.0
#06 DT661/Wxd26-11	51.0	-3.2	32.6	9.0	227.0
#07 DT661/Wxd26-12	49.5	-1.8	31.6	9.1	243.0
#09 DT661/Wxd26-22	49.5	-2.2	31.9	8.4	236.0
#14 DT661/Wxd33-7	50.3	-3.1	33.1	7.0	230.0
#29 JWD-230	50.7	-2.8	33.2	8.8	238.0
#31 JWD-230	51.1	-2.9	32.8	8.2	232.0
#35 JWD-239	50.4	-1.8	31.8	9.3	240.0
#39 JWD-119	49.7	-2.1	29.1	10.1	239.0
#41 JWD-188	50.2	-2.5	31.4	10.0	232.0
#43 JWD-238	50.9	-2.2	32.1	8.4	238.0

Among the conventional durum pastas, sample No.47 was the yellowest, with a vivid color. Among the waxy durums, sample Nos.4, 7, 9 showed more specks which, were easily detected. Sample Nos.4, 7, 9, 35, 39 had a slightly dull color. Other waxy durum gave an acceptable color. Although the color was not pronounced, No.31 was slightly brighter. Conventional durum Nos.45, 46, 48, 49, and the waxy durum Nos.6, 14, 29, 31 showed slightly lower a* values. Sample No.47 (AC Navigator) gave higher a* and b* values, which was easily distinguishable with the naked eye. The waxy durum samples gave rather higher L* values, which indicates that the waxy durum pastas were lighter or paler in color. No.39 had the lowest b* value.

The waxy durum pasta, although cooking time was shorter than the conventional durum, showed the same level of cooking yields as the CWAD cargo sample. There were no large differences in cooking yield among the waxy durum samples. Waxy durum samples, however, had a higher cooking loss, especially sample Nos.39 and 41.

The waxy durum pasta had a softer texture with less springiness, less bite, and strong glutinosity. Although there were some differences among waxy durum samples, they all were quite different from the sensory quality of CWAD spaghetti. Normally, the lowest scores (=1) or even a score or 2 is not given to test samples. The waxy durum received many "1" scores, which means the eating quality of pasta from waxy durum is not what one would expect from spaghetti. The waxy samples, when cooked "al dente", resulted in the core of the spaghetti strand giving an inferior bite feeling, and more stickiness (glutinosity), which resulted in the low scores. Also, cooked pasta strands from the waxy durum quickly became softer (like overcooked pasta).

Table 12. Sensory scores for 2000 crop year samples.

Pasta Sample	Color	Firmness	Springi-ness	Mouthfeel at bite	Glutinosity	Total
Ref. CWAD Cargo	4.0	4.0	4.0	4.0	4.0	20.0
#45 Kyle	3.5	4.0	4.0	3.8	3.5	18.8
#46 AC Morse	3.8	4.0	4.3	3.8	4.3	20.2
#47 AC Navigator	4.8	3.5	3.5	4.3	4.3	20.4
#48 AC Melita	3.8	4.0	3.5	4.3	4.0	19.6
#49 AC Avonlea	3.8	4.5	4.3	4.3	3.5	20.4
#04 DT661/Wxd26-5	3.5	1.5	2.0	2.0	1.8	10.8
#06 DT661/Wxd26-11	3.3	1.8	2.0	2.0	1.5	10.6
#07 DT661/Wxd26-12	3.0	1.8	1.5	2.0	1.5	9.8
#09 DT661/Wxd26-22	3.0	1.0	1.5	2.3	1.5	9.3
#14 DT661/Wxd33-7	4.0	1.0	1.5	2.0	1.3	9.8
#29 JWD-230	4.0	1.0	1.3	1.5	1.5	9.3
#31 JWD-230	4.0	1.8	1.8	1.5	2.0	11.1
#35 JWD-239	3.5	1.3	1.3	1.8	1.0	8.9
#39 JWD-119	3.3	1.5	1.3	1.8	1.3	9.2
#41 JWD-188	3.5	1.5	1.8	1.5	2.0	10.3
#43 JWD-238	3.5	1.3	1.5	2.0	1.8	10.1

Table 13. Pasta Rheology data for the 2000 crop year samples.

Pasta Sample	Tensile Test			
	Rate of Extension %	Tensile Strength g/cm2	Strength/ Extension	Shear Strength g/cm2
Ref. CWAD Cargo	55.6	696.5	12.5	2052.8
#45 Kyle	59.7	728.4	12.2	1856.8
#46 AC Morse	63.8	749.0	11.7	1899.6
#47 AC Navigator	61.9	696.0	11.2	1644.2
#48 AC Melita	82.3	725.3	8.8	1573.4
#49 AC Avonlea	73.3	801.9	10.9	1923.6
#04 DT661/Wxd26-5	66.9	334.0	5.0	1411.7
#06 DT661/Wxd26-11	73.2	407.5	5.6	1457.8
#07 DT661/Wxd26-12	102.4	360.5	3.5	1035.4
#09 DT661/Wxd26-22	69.2	322.1	4.7	1164.7
#14 DT661/Wxd33-7	76.1	298.3	3.9	967.8
#29 JWD-230	100.3	305.3	3.0	963.5
#31 JWD-230	100.7	284.9	2.8	998.5
#35 JWD-239	80.1	278.1	3.5	846.2
#39 JWD-119	74.0	266.3	3.6	884.0
#41 JWD-188	86.6	300.4	3.5	952.0
#43 JWD-238	80.2	261.2	3.3	876.1

The waxy durum samples had higher extension values, and a lower tensile strength and shear strength. Although, protein level generally affects the pasta quality, the waxy durum samples, which were higher in protein than commercial CWAD, resulted in pasta with totally different quality. Starch characteristics might largely affect the pasta rheology. Also, the quality of waxy durum protein may different from the protein of conventional durum. The "tensile strength/extension" value is used as an indicator of noodle/pasta quality. Usually, "tensile strength/extension" values of 10 or more are required for good spaghetti quality, and a value of less than 4 is required for Japanese salted noodle (Udon). The waxy durum samples all showed very low values. The samples Nos.7, 14, 29, 31, 35, 39, 41 and 43 can be considered as having an Udon noodle texture, rather than pasta texture.

2.a. Partially waxy durum wheat doubled haploid lines

A series of 167 doubled-haploid lines from crosses between AC Avonlea and a waxy durum wheat were produced at the CDC by K. Hatta. These lines were grown in New Zealand during the winter of 2000/200. All lines were subjected to Falling Number testing while 67 were subjected to SDS – PAGE electrophoresis and 129 to amylose measurement analysis.. The DH lines were first subjected to a FN test to identify fully waxy lines. As expected, ¼ of the lines were fully waxy. This was confirmed by SDS PAGE analysis. Four of the fully waxy lines were subjected to amylose measurement. The results of that work are presented in Table 4. It is apparent that we have been able to identify partially waxy genotypes. The amylose measurements are an estimate as they were carried out on meal and adjusted to a 70% starch content. However, the relative differences are valid for interpretation purposes. A null wx mutation in the A genome reduced amylose content by 3% while the null B condition reduced amylose by 7% units. These partially waxy lines will be subjected to more detailed analysis using seed produced at Saskatoon in 2001.

Table 14. Phenotyping of doubled-haploid lines grown in 2001 for starch profile

Genotype SDS-PAGE		Estimated amylose content %	SE	Falling Number sec	SE	Number of Lines
null AB	waxy	0.8	0.2	62.2	0.1	4
null A	partially wx	24.0	0.4	388.3	11.2	17
null B	partially wx	20.4	0.5	376.3	15.8	8
AB	wild type	27.4	0.6	399.2	8.1	21

SE = Standard Error

2.b. 2001 Partially waxy durum detailed quality evaluation

Ten conventional durum wheat grain samples (5 samples each of AC Melita and AC Avonlea) and 100 partially waxy DH durum lines, (50 lines of SDS-PAGE band A present, and 50 lines of SDS-PAGE band B present) were provided to NiPPN by the CDC program. One sample each from Melita and Avonlea, eight samples each from band A lines and band B lines were tested. As a reference, a commercial CWAD cargo sample was added to the 18 test samples.

Due to the limited sample sizes (due to the 2001 drought at Saskatoon) no whole grain analyses were performed except for moisture content, which was used for tempering wheat samples for experimental milling, and only limited analyses were done on the resulting flour. Flour samples were obtained using a Brabender Quadrumat Jr. experimental mill. Spaghetti was prepared using small scale mixing and extrusion apparatus.

The following results were obtained from very small-scale experiments, and no evaluation on wheat quality was performed. Therefore, larger-scale experiments are needed to verify the following results.

Flour protein levels ranged very widely among the samples (11.3-18.1%). Flour yields of partially waxy durum were higher than the previously reported completely waxy samples. #003-F4573, #073-F4748, #012-F4613 and #018-F4622 showed higher flour yields, but #030-F4657 and #084-F5346 showed lower flour yields.

The control samples (AC Melita and AC Avonlea) had a slightly lower amylose content, compared to the CWAD cargo sample. Partially waxy lines with SDS-PAGE band A showed lower amylose content than the partially waxy lines with band B. Partially waxy lines with band B showed approximately same level or slightly lower level of amylose content, compared to the reference and control samples. Sample #012-F4613 had a higher amylose content than Melita and Avonlea. Bran specks in the flour samples seemed to be less frequent than for previously reported completely waxy samples.

The amount of water added to the flour during mixing was 32% for the normal durum, and 30% for the waxy durum (16% flour moisture basis). With these water absorptions, dough from some samples were tough and required a longer time to extrude (#084-F5346, #085-F5363, #094-F5640, #095-F5642). On the other hand, sample #030-F4657 required less time to extrude, possibly be due to its lower protein content.

No spaghetti samples showed excessive speckling. The color of dried spaghetti samples #012-F4613, #084-F5346, #085-F5363, #094-F5640 were less yellow and whiter, #066-F4731, #079-F5297 were reddish, #079-F5297, #095-F5642 were duller in color, the CWAD cargo sample and #066-F4731 were deeper in color. Other samples showed better color, especially #001-F4571, #101-F4245 (=Melita), #106-F4575 (=Avonlea) had a brighter yellow color.

As for eating quality, all the partially waxy samples except #066-F4731, were glutinous compared to the reference CWAD sample. When we evaluated those partially waxy samples as "conventional pasta", in comparison to CWAD the glutinous sample gave different bite, resulting in a slightly lower score. The glutinous characteristic, however, is not supposed to be an inferior quality factor, if the pasta also has optimum firmness and springiness. If the pasta is characterized by excessive glutinosity and/or not enough firmness and springiness, glutinosity would be a deleterious factor for "conventional" pasta quality.

The partially waxy samples #001-F4571, #048-F4696, #079-F5297, #084-F5346, #094-F5640, #095-F5642 showed glutinosity with firmness and springiness. When pasta color was taken into consideration, #001-F4571 would be the most preferable among the tested partially waxy lines, followed by #079-F5297. Sample #066-F4731 resulted gave a higher evaluation score, because this sample showed slightly more firmness and slightly more springiness with glutinosity of only the same level as that of the CWAD sample.

Compared to fully waxy durum samples, pasta from the partially waxy samples showed very close, but slightly different texture to the "CWAD pasta".

Flour protein level ranged widely from 11.3% to 18.1%. The commercial CWAD cargo sample (reference) and control samples (#101 Melita, #106 Avonlea) had 12.3 to 13.7% protein. The control samples were slightly lower in protein than the cargo sample. Compared to those reference and control samples, #079-F5297 had a very high protein level. #084-F5346 and #094-F5640 also had a high protein level. #030-F4657 had a lower protein level.

Flour yields of partially waxy durum samples were 59.5 to 67.8%, which are higher than those previously obtained for fully waxy durum samples. There seems to be no differences in flour yield between lines with SDS-PAGE band A and lines with band B. Compared to the normal durum samples, #003-F4573, #073-F4748, #012-F4613 and #018-F4622 showed higher flour yields, but #030-F4657 and #084-F5346 showed lower flour yields.

The control samples (Melita and Avonlea) showed slightly lower amylose content than the CWAD cargo sample. Among the partially waxy lines, samples with SDS-PAGE band A showed lower values (28.1-30.3) than the samples with band B (28.4-32.6). Samples with band B showed approximately same or slightly lower level of amylose content, compared to the reference and control samples. Among the samples with band A, #029-F4658 showed slightly higher amylose content. Among the samples with band B, #030-F4657, #085-F5363 and #095-F5642 showed lower amylose contents, #012-F4613 showed higher value than Melita and Avonlea, and the rest showed about the same level with Melita and Avonlea.

Table 15. Experimental Milling and Flour Data, 2001 crop year

No.	2001 Field no.	SDS-PAGE band presence	Flour Yield %	Bran Yield %	Moisture %	Protein % 13.5%mb	Amylose % in Starch
#003	F4573	A	67.8	32.2	15.6	12.6	28.5
#017	F4620	A	64.9	35.1	15.7	12.6	28.7
#029	F4658	A	64.9	35.1	15.6	12.5	30.3
#058	F4713	A	64.5	35.5	15.6	13.6	28.9
#073	F4748	A	66.3	33.7	15.5	12.3	28.1
#079	F5297	A	61.7	38.3	15.3	18.1	28.8
#084	F5346	A	59.7	40.3	15.4	15.9	28.5
#094	F5640	A	62.2	37.8	15.3	16.1	29.6
#001	F4571	B	63.5	36.5	15.4	12.5	30.9
#012	F4613	B	67.7	32.3	15.5	12.9	32.6
#018	F4622	B	66.9	33.1	15.6	12.4	30.9
#030	F4657	B	59.5	40.5	15.5	11.3	28.4
#048	F4696	B	64.5	35.5	15.4	12.3	31.3
#066	F4731	B	62.8	37.2	15.3	13.9	30.9
#085	F5363	B	62.2	37.8	15.2	14.7	29.2
#095	F5642	B	62.7	37.3	15.2	15.0	30.0
#101	F4525	Melita	63.4	36.6	15.5	12.3	31.3
#106	F4575	Avonlea	65.5	34.5	15.4	12.4	30.7
Ref	CWAD	Cargo	64.5	35.5	15.6	13.7	33.3

Protein : combustion method

Pasta processing was performed using a small Farinograph bowl. The amount of water added at the mixing stage weas32% for normal durum, and 30% for the partially waxy durum (both at 16% moisture basis). The difference in water absorption might somewhat affect the dough properties.

At the mixing stage, CWAD, #106-F4575, and #066-F4731, #084-F5346, #085-F5363, #094-F5640, #095-F5642 seemed to be slightly lower in water absorption. However, partially waxy lines, except #066-F4731, seemed to give a higher load to the mixer, which may indicate that the doughs were tougher or sticky. At pressing stage, dough of #084-F5346, #085-F5363, #094-F5640, #095-F5642 seemed to be tougher than normal durum.

At the extrusion process, there were differences in time required for extruding dough. #101-F4525 and #030-F4657 required approximately half the time of normal durum. #084-F5346, #085-F5363, #094-F5640, #095-F5642 required approximately 1.5 to twice the times of normal durum. Each sample was extruded at 9.8Mpa.

Previously reported waxy lines dried slowly when cooked pasta was left in the room, and had a glossy appearance. The partially waxy durum did not show these tendencies, which may indicate that partially waxy durum may have approximately the same water holding capacity as normal durum.

The pasta strands of #101-F4525(Melita) and #030-F4657, which required less time to extrude, resulted in smaller diameters. However, samples that required more time to extrude did not result in a larger diameter, which is different from the case in completely waxy samples.

Each sample tested, including partially waxy lines, did not show many specks. Samples #012-F4613, #084-F5346, #085-F5363, and #094-F5640 showed less yellowness, especially #085-F5363 appeared

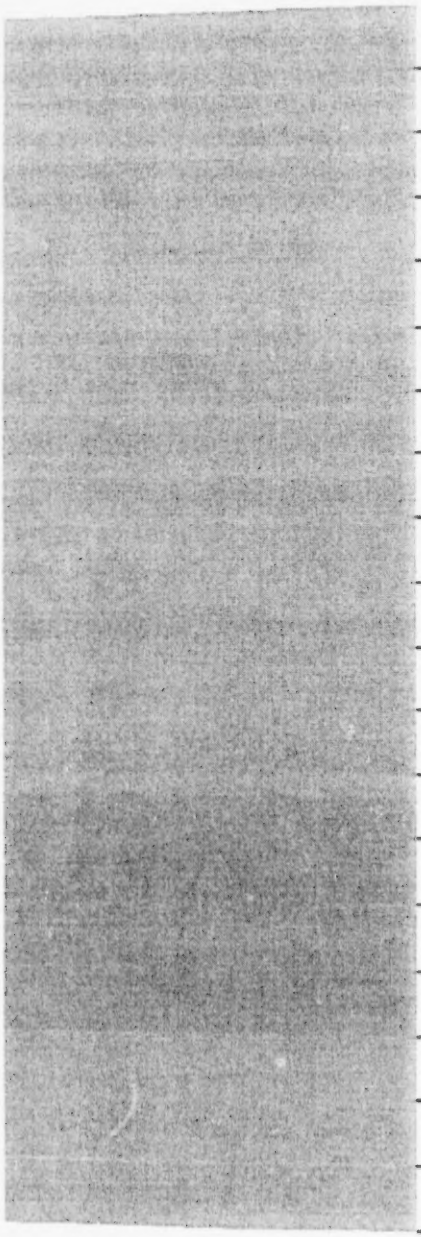
whiter than the others. Samples #066-F4731 and #079-F5297 showed slightly reddish color, and samples #079-F5297 and #095-F5642 had a duller color. CWAD and #066-F4731 had a deeper color. Other samples had a better color. Samples #001-F4571, #101-F-4525 Melita, and #106-F4575 Avonlea had a brighter yellow color. The a* value indicates that #029-F4658, #030-F4657, #048-F4696, and #066-F4731 are reddish, compared to the CWAD control. The b* value indicates that #001-F4571 and #073-F4748 are more yellow than CWAD. The other partially waxy lines showed lower a* values and b* values than CWAD. Especially #085-F5363 gave the lowest b* value, which agreed with visual observations.

The L* and C* values indicate that #001-F4571 and #073-F4748 were brighter and more vivid, and #085-F5363 was duller.

Table 16. Dry Pasta Diameter and Color, 2001 crop year

No.	2001 Field no.	SDS-PAGE band presence	Pasta Strand		Pasta Color			
			Diameter	SD	L*	a*	b*	C*
#003	F4573	A	1.728	0.008	51.35	-2.10	36.24	36.30
#017	F4620	A	1.740	0.007	50.70	-2.56	34.92	35.01
#029	F4658	A	1.726	0.006	50.77	-1.21	37.16	37.18
#058	F4713	A	1.735	0.006	51.35	-1.68	36.79	36.83
#073	F4748	A	1.734	0.007	51.23	-1.88	38.58	38.63
#079	F5297	A	1.762	0.007	49.90	-1.54	35.02	35.05
#084	F5346	A	1.747	0.014	50.41	-1.95	33.03	33.09
#094	F5640	A	1.745	0.010	49.86	-2.25	33.69	33.77
#001	F4571	B	1.756	0.011	50.20	-1.70	39.66	39.70
#012	F4613	B	1.755	0.009	50.64	-1.71	33.25	33.29
#018	F4622	B	1.760	0.008	50.80	-1.95	35.87	35.92
#030	F4657	B	1.695	0.007	50.88	-1.09	35.19	35.21
#048	F4696	B	1.742	0.008	50.22	-1.01	37.24	37.25
#066	F4731	B	1.757	0.010	50.05	-0.36	36.85	36.85
#085	F5363	B	1.765	0.018	50.48	-2.04	30.58	30.65
#095	F5642	B	1.762	0.020	49.61	-1.56	32.88	32.92
#101	F4525	Melita	1.711	0.010	51.53	-2.15	37.36	37.42
#106	F4575	Avonlea	1.755	0.011	50.97	-2.43	36.43	36.51
Ref	CWAD	Cargo	1.750	0.008	50.24	-1.50	37.35	37.38

Diameter is an average of 25 pasta strands.



Appearance of pasta strands

The cooking loss of partially waxy pasta was at the same level or lower than for the CWAD control, which was different from the observation for fully waxy lines. Based on the cooking yield data, #073-F4748 might be cooked slightly longer than the optimum, and #012-F4613 might be cooked slightly shorter than the optimum.

Table 17. Cooking characteristics of partially waxy durum wheat lines, 2001 crop year

No.	2001 Field no.	SDS-PAGE band presence	Cooking Time	Cooking Yield %	Cooking Loss %
#003	F4573	A	8'30"	246	7.4
#017	F4620	A	8'00"	246	7.0
#029	F4658	A	8'30"	243	7.1
#058	F4713	A	8'30"	245	6.8
#073	F4748	A	8'30"	255	6.1
#079	F5297	A	9'30"	234	6.6
#084	F5346	A	9'30"	245	6.8
#094	F5640	A	9'30"	245	7.7
#001	F4571	B	8'30"	241	6.6
#012	F4613	B	8'30"	230	7.1
#018	F4622	B	8'30"	238	7.2
#030	F4657	B	8'00"	241	7.5
#048	F4696	B	8'30"	241	7.7
#066	F4731	B	8'30"	245	5.8
#085	F5363	B	9'30"	248	7.1
#095	F5642	B	9'30"	238	6.8
#101	F4525	Melita	9'00"	248	7.0
#106	F4575	Avonlea	9'00"	245	7.2
Ref	CWAD	Cargo	9'00"	236	7.8

As previously reported, fully waxy durum pasta had a softer texture, less springiness, less bite, and strong glutinosity. The partially waxy lines tested in 2002 did not exhibit those excessive waxy characteristics, and were much more suitable for pasta production. Compared to CWAD wheat, all the partially waxy samples, except #066-F4731, had slightly glutinous characteristics. However, when we evaluated those partially waxy samples as "conventional pasta", in comparison to the CWAD control, the bite differed (due to the glutinous feeling) and resulted in lower scores for the partially waxy samples. The glutinous characteristic, however, is not supposed to be an inferior quality factor, if the pasta also has an optimum firmness and springiness. If pasta is glutinous but lacks firmness and/or springiness, glutinosity will be deemed an inferior quality factor. The partially waxy samples #001-F4571, #048-F4696, #079-F5297, #084-F5346, #094-F5640, and #095-F5642 showed glutinosity with firmness and springiness. When pasta color was taken into consideration, #001-F4571 would be the most preferable of the tested samples, followed by #079-F5297. Sample #066-F4731 had a higher score. This sample was slightly firmer and slightly more springy with a glutinosity similar top that of CWAD wheat. The control samples #101-F4525 Melita and #106-F4575 Avonlea also showed slightly glutinous properties. In the evaluation of 2000 crop year samples, AC Avonlea also showed a slight glutinosity, but AC Melita did not. The samples tested, except for the cargo CWAD, were grown in yield trial plots, and might be somewhat different in quality from commercially grown durum wheat.

In general, the partially waxy samples tested did not show excessive waxy characteristics, and were more preferable for pasta manufacturing, compared to the completely waxy lines. However, the partially waxy lines lacked novel characteristics from already existing durum, therefore, utilization of partially waxy lines could be limited to the same or similar use to that of conventional durum wheat

Table 18. Sensory Quality Scores, 2001 crop year.

Note: Higher score point does not necessarily mean that a certain characteristic is better than the others. Score 1.0 (not preferable) – Score 4.0 (control) – Score 7.0 (preferable)

No.	2001 Field no.	SDS-PAGE band presence	Color	Firmness	Springi-ness	Mouthfeel at bite	Gutinosity	Total
#003	F4573	A	4.0	3.0	3.7	3.7	3.0	17.4
#017	F4620	A	4.0	3.3	4.0	3.3	3.0	17.6
#029	F4658	A	3.7	3.3	3.7	4.0	3.3	18.0
#058	F4713	A	4.0	3.3	4.3	3.7	3.3	18.6
#073	F4748	A	4.7	3.3	4.0	3.7	3.3	19.0
#079	F5297	A	3.3	5.0	5.0	4.0	4.0	21.3
#084	F5346	A	3.3	4.0	4.3	4.0	3.7	19.3
#094	F5640	A	3.7	4.7	4.0	4.0	3.3	19.7
#001	F4571	B	4.3	4.7	5.0	4.0	4.0	22.0
#012	F4613	B	3.3	3.7	4.3	4.0	3.3	18.6
#018	F4622	B	4.3	3.3	4.0	3.7	3.7	19.0
#030	F4657	B	3.3	4.0	3.7	3.7	4.0	18.7
#048	F4696	B	4.7	4.3	4.7	3.3	3.3	20.3
#066	F4731	B	4.0	4.3	4.3	4.0	4.0	20.6
#085	F5363	B	3.0	3.7	4.0	4.0	3.7	18.4
#095	F5642	B	3.7	5.0	4.3	4.0	3.7	20.7
#101	F4525	Melita	4.3	3.3	3.7	4.0	4.0	19.3
#106	F4575	Avonlea	4.3	3.7	4.3	4.0	3.7	20.0
Ref	CWAD	Cargo	4.0	4.0	4.0	4.0	4.0	20.0

The rheology analyses were performed on "water cooled" spaghetti strands, to eliminate quality changes due to the pasta temperature drop during analysis. Therefore, the core of the pasta strand, which usually disappears with time, can be left in the strand and may affect some strength-related results.

Fully waxy lines tested from the 2000 crop year had a lower tensile strength and higher extension rate. Some of the partially waxy lines tested from the 2001 plots, however, (#079-F5297, #084-F5346, #085-F5363, #094-F5640, #095-F5642) had a tensile strength greater than that of CWAD samples. Sample #030-F4657 showed approximately half of the tensile strength value of CWAD. The value "tensile strength/extension" is used as an indication of noodle/pasta quality. A value of 10 or more is said to be necessary for good spaghetti quality while a value of less than 4 is said to be necessary for Japanese white salted noodle (Udon). #073-F4748 showed a lower "tensile strength/extension" value and #101-F4525 Melita showed a slightly lower value. The other samples had a "tensile strength/extension" value of greater than 10.

The samples #079-F5297 and #095-F5642 both rated as "having firmness" during sensory tests, showed a higher shear strength than CWAD. On the other hand, sample #003-F4573, which was evaluated as "lacking firmness" had a lower shear strength. However, #030-F4657, which was evaluated as having a "similar firmness to CWAD" also showed a lower shear strength.

Table 19.Tensile Test and Shear Test Data, 2001 crop year

No.	2001 Field No.	SDS-PAGE band presence	Tensile Test			Shear Strength g/cm2
			Rate of Extension %	Tensile Strength g/cm2	Strength/ Extension	
#003	F4573	A	39.9	405.3	10.2	1544.4
#017	F4620	A	19.0	488.5	25.7	2058.7
#029	F4658	A	23.4	458.3	19.6	1792.5
#058	F4713	A	27.4	446.3	16.3	1665.3
#073	F4748	A	46.9	400.0	8.5	1778.0
#079	F5297	A	62.2	779.1	12.5	2578.3
#084	F5346	A	72.9	750.6	10.3	2217.8
#094	F5640	A	72.5	780.9	10.8	2163.0
#001	F4571	B	37.7	548.2	14.5	2139.5
#012	F4613	B	44.0	578.8	13.2	2070.1
#018	F4622	B	43.9	582.7	13.3	2143.8
#030	F4657	B	19.6	386.5	19.7	1516.0
#048	F4696	B	47.7	538.3	11.3	1779.0
#066	F4731	B	40.4	626.4	15.5	2319.8
#085	F5363	B	62.2	776.1	12.5	2232.8
#095	F5642	B	57.5	804.2	14.0	2313.8
#101	F4525	Melita	64.6	625.9	9.7	1702.8
#106	F4575	Avonlea	68.5	712.3	10.4	2052.2
Ref	CWAD	Cargo	55.0	735.4	13.4	2044.5

CONCLUSIONS

All the pasta samples made from waxy durum had a totally different texture relative to CWAD wheat. The protein level of the year 2000 waxy durum samples was high, however, high protein level was not reflected in the pasta quality. The appearance of the waxy durum pasta was, in general, acceptable, although some samples showed more specks and some had a dull color. Apart from the texture and sensory quality, there were some differences among waxy durum samples. Based on the color/speck of the dried/cooked pasta, waxy durum samples No.6, 14, 29, 31, 41 and43 are thought to be better than the others. However, No.41 was higher in cooking loss, and dough from Nos.29, 31 and 43 were too soft for pasta processing. The remainder, No.6 (DT661/Wxdur26-11) and No.14 (DT661/Wxdur33-7) seemed better than the others. However, these two lines also need improvement in texture (or eating quality), and they both (especially No.14) might have less tolerance for sprouting. As for the pasta processing quality, the waxy durum may have some trouble in regards to strand stretching during drying, due to dough weakening during heating experienced during extrusion process. Thus, samples with stronger dough properties are thought to be more desirable when combined with the fully waxy trait.

Partially waxy durum wheat appears to have more potential as it still produces a pasta-like product despite having a lower amylose content. Some partially waxy lines had a shorter cooking (-12%) time and lower cooking losses than conventional durum. The potential energy savings, when multiplied over pasta-consuming households could be significant. This facet of partially waxy wheat needs to be more extensively studied to confirm or refute our findings.

This project demonstrated that it is possible to develop low amylose durum wheat lines that are of near-varietal potential. Further improvements in the agronomic performance or waxy wheat should be

possible with limited backcrossing to recently developed CWAD wheat cultivars. Although fully waxy durum wheat does not appear suitable for pasta or noodle production it may still play and role in providing a product for blending purposes. These research findings are based on small-scale laboratory trials and will need to be validated at the pilot-scale.

IMPACT ON SASKATCHEWAN AGRICULTURE

The work conducted during the course of this project helped identify waxy and partially waxy durum doubled haploid lines that could lead to the development of a variety or varieties. At the very least, these experimental lines can be used as parental material in a new round of population development. In essence, the experimental material could be considered to be 95% variety-ready. The eventual release of durum with low amylose content should result in crop diversification options for wheat.

ACKNOWLEDGEMENTS

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ITEM "B". Deviations from original workplan - NIL

ITEM "C". Successful development of more than 2000 doubled haploid lines of durum
Successful 2000, 2001, 2002 plot harvest, analysis of field data and detailed quality analyses

ITEM "D". Equipment-NIL.

ITEM "E". Personnel -

R. Xiao (September 1, 2000 – January 31, 2002)-30%
(Technician)

H. Braitenbach (January 1, 2002 – June 30, 2002) -100%
(Technician)

M. Grieman (January 1, 2003 - January 31, 2003) – 100%
(Technician)

Other contributors:

S. Fox (September 1, 2000 – July 1, 2001) - 5%
P. Hucl (July 1, 2001 – December 31, 2002)-3 %
C. Perron (May 1, 2001 – December 31, 2002) – 5%

ITEM "F". Expense statement – to follow